sustainability

MDPI

*Article*

# A Survey and Analysis on Electricity Consumption of Raw Material Mill System in China Cement Industry between 2014 and 2019

**Ruonan Meng [1,2], Qinglin Zhao [1,2,*], Miaomiao Wu [1,2], Quanming Long [1,2] and Mingkai Zhou [1,2]**

[1] State Key Laboratory of Silicate Materials for Architecture, Wuhan University of Technology, Wuhan 430070, China; mengruonan@whut.edu.cn (R.M.); mmwu@whut.edu.cn (M.W.); 257216@whut.edu.cn (Q.L.); zhoumk@whut.edu.cn (M.Z.)
[2] School of Materials Science and Engineering, Wuhan University of Technology, Wuhan 430070, China
* Correspondence: zhaoqinglin@whut.edu.cn; Tel.: +86-1530-711-0820

**Abstract:** In the whole process of cement production, the electricity consumption of a raw material mill accounts for about 24% of the total. Based on the statistics of the electricity consumption of the raw material mill system of 1005 production lines in China between 2014 and 2019, it is found that the average electricity consumption of the raw material preparation process of all clinker production lines between 2014 and 2019 was 25.2 kWh/t. The average electricity consumption of different-tonnage production lines varies with time. In comparison with high-tonnage ones, the electricity consumption of low-tonnage production lines has wider distribution. The average electricity consumption of raw material mill dropped from 30.88 kWh/t in 2014 to 16.13 kWh/t in 2019, with a drop of more than half. At present, the raw material preparation process of new drying-process cement production enterprises mainly includes middle unloading drying tube mill raw material preparation system, vertical mill raw material final grinding system, and roller press raw material final grinding system. This paper compares the characteristics of several grinding systems and summarizes their influence on the electricity consumption.

**Keywords:** raw material mill; electricity consumption; middle unloading drying tube mill; vertical mill; roller press



**Citation:** Meng, R.; Zhao, Q.; Wu, M.; Long, Q.; Zhou, M. A Survey and Analysis on Electricity Consumption of Raw Material Mill System in China Cement Industry between 2014 and 2019. *Sustainability* **2021**, *13*, 1126. https://doi.org/10.3390/su13031126

Academic Editor: Marc A. Rosen
Received: 14 December 2020
Accepted: 18 January 2021
Published: 22 January 2021



## 1. Introduction

China is the largest producer of cement in the world [1]. The cement production process consists of three mills and one kiln, in which the total electricity consumption of the three-stage mill of raw material, coal powder, and cement products accounts for about 70% of the total electricity consumption per ton of cement. The three mills all involve the electricity consumption caused by the grinding technology and the grinding process. In grinding raw material and grinding cement final products, the technology focus and process selection of grinding are different because of different grinding materials. In terms of the development trend of raw material grinding technology home and abroad, it is mainly reflected in the following aspects [2,3]:

1. The first is the expanded improvement of the traditional grinding system and the combined use of high-efficiency vertical mills, roller presses, and other types which makes that the high yield and low consumption of the raw material preparation process have reached a considerable level in many cement plants. As for different special materials, it has a wide range of adaptability.
2. The second is the application of new equipment and new technology, making the raw material mill system abundant and perfect. The integration of ball mill drying and grinding, promotion of a vertical mill, which is equipped with a new type of powder separator and suitable for high moisture content, and the utilization of pre-

decomposition waste gas as a drying heat source for suspension preheater kiln, etc., have promoted the development of raw material preparation technology.

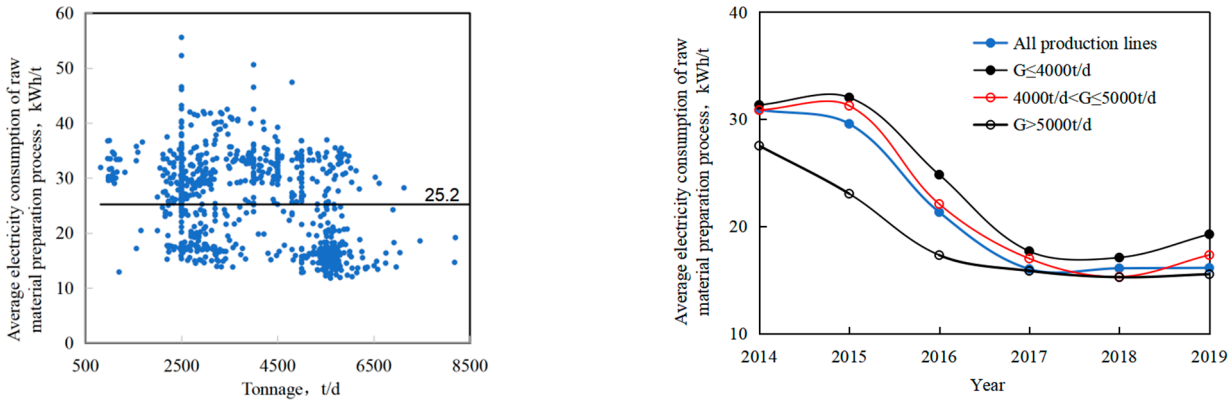
3. The third is the gradual advancement of the intelligent operation and control process. The overall automation in China cement production has been much advanced. The automatic control of the mill operating system, the analysis and detection of raw material, and batching and metering have been popularized. At this stage, the main focus is on the development from general automatic control to the application of artificial intelligence to carry out professional diagnosis, and cloud computing, etc., combing with analog computing to optimize production and realize intelligent control.
4. The fourth is the shift from simple emissions-reducing to comprehensive attention to the compatibility with the ecological environment, and the treatment and utilization of waste gas and other wastes to improve the environment.
5. The fifth is that the raw material grinding equipment continues to be large-scale, and that the single-machine capacity continues to increase to meet the large-scale demand for cement production. At the same time, the focus is on improving the reliability and utilization of equipment and reducing material inventory as much as possible.

In order to fully understand the state of raw material grinding technology and energy consumption in China, we analyzed the operating status of the raw material mill systems in the recent years. The overall electricity consumption of a raw material mill in China is clarified. Different raw material mill systems are compared and analyzed as to understand the advantages and disadvantages of different raw material mill systems and to discuss the main factors that affect raw material mill energy consumption. Finally, we forecast the improvement points of raw grinding technology in the near future, providing a reference for the industry production to further reduce energy consumption and achieve higher efficiency.

## 2. Operating Status of Raw Material Mill System in China Cement Industry

In cement production, the energy consumption of the grinding process is mainly reflected in the links of raw material preparation, coal powder preparation, and cement grinding. Though raw material grinding does not require higher specific surface area, strict particle gradation, particle morphology, and other indicators like cement products, the 80 μm sieve residue, especially the 200 μm sieve residue, is strictly controlled to meet the requirements of kiln calcination. The electricity consumption of raw material mills accounts for about 24% of the total electricity consumption of cement. Therefore, from this aspect, the development of raw material grinding technology will directly affect the development of the cement industry. How to improve the efficiency of raw material mills, reduce grinding electricity consumption, and increase the output per mill is also the focus of the industry development [4,5]. Therefore, a comparative analysis of the electricity consumption of raw material mill systems of different enterprises is of great significance in saving energy.

Between 2014 and 2019, the project team collected production data through thermal calibration of cement production lines, and visited and mastered the electricity consumption of about 1005 clinker production lines in the raw material preparation process. Refer to Figure 1 for the electricity consumption of the raw material preparation process in different tonnage production lines, and the average electricity consumption of the raw material preparation process in different years. Analyzing the data, the following conclusions can be found:




(**a**) in different tonnage production lines (**b**) in different years

**Figure 1.** Electricity consumption of the raw material preparation process between 2014 and 2019.

(1) As can be seen from the data distribution chart in Figure 1a, the average electricity consumption of the raw material preparation process of all clinker production lines between 2014 and 2019 was 25.2 kWh/t. The average electricity consumption of different-tonnage production lines varies with time. In comparison with high-tonnage ones, the electricity consumption of low-tonnage production lines has wider distribution and higher average value. This shows that in recent years, with the progress of China grinding technology and the overall promotion of large-scale production line equipment, China's overall reduction work in terms of raw material mill electricity consumption has been continuously improved.

(2) Due to the large fluctuations in the electricity consumption of the raw material mill, in order to clarify the overall change of electricity consumption, the average electricity consumption of the raw material mill in different years is sorted and analyzed. It can be seen from Figure 1b that for different tonnage production lines, there are obvious differences in the average electricity consumption of raw material mills in different years. Among them, the average electricity consumption of raw material mills of the enterprises with larger tonnage ($G \geq 5000$ t/d) compared with that of less than 5000 t/d, the former has certain advantages. Moreover while the average electricity consumption of different tonnage production lines varies greatly in 2014, the average electricity consumption of different tonnage production lines has become significantly smaller after 2017. After 2017, with the increase of the tonnage of the production line, the average electricity consumption of raw material mill will also be reduced, but the gap between the average electricity consumption of raw material mill for different tonnage production lines has been significantly reduced. This shows that the increase in production line tonnage has no particularly prominent advantages in reducing the average electricity consumption of raw material mill.

(3) As time went by, between 2014 and 2019, the average electricity consumption of raw material mill decreased significantly in different years. This indicates that the average electricity consumption of raw material mill has dropped from 30.88 kWh/t in 2014 to 16.13 kWh/t in 2019, a drop of more than half. This is also the role of the full external circulating raw material vertical mill final grinding system and roller press final grinding system being greatly introduced in the industry. Among them are the typical enterprises with an actual daily output of less than 4000 t/d, most of which are the old enterprises with an earlier construction period. Compared with the newly-built enterprises with an actual daily output more than 5000 t/d, their change in electricity consumption of raw material mill grinding with the number of years can better reflect the technological progress of the industry. Combining the field survey and the comparison of 1005 sets of thermal calibration data, it can be seen that the raw material mill electricity consumption of the enterprises with an actual daily output of less than 4000 t/d reached 55.58 kWh/t in 2014, and the lowest was 17.00 kWh/t. Through continuous technological transformation, the highest power consumption of raw material mills in 2019 is only 29.50 kWh/t, and the lowest

is 16.07 kWh/t. For the companies with an actual daily output of more than 5000 t/d, the lowest electricity consumption for raw material mills is only 12.33 kWh/t. It can be seen that through a five-year plan, the energy-saving effect of raw material mills through technological improvement and promotion is very obvious.

In summary, as the new drying-process cement technology becomes better and better, the improvement and promotion of raw material grinding technology has made significant progress. Throughout the development process of raw material grinding technology, it has gone through two major stages of change. The first development stage is from 1950s to 1970s, the drying and crushing steel ball mill (including: air sweeping and tail unloading, middle unloading lifting cycle mill). The second development stage is roller mill and roller press grinding technology from the 1970s to the present [6]. In accordance with the survey results, the current raw material preparation process of domestic new drying-process cement production enterprises mainly includes a middle unloading drying tube mill raw material preparation system, a vertical mill raw material final grinding system, a roller press raw material final grinding system, and several other mill systems. The lowest power consumption for grinding and the most significant power-saving effect is the roller press final grinding system which is currently reported [7]. At the same time, the large-scale equipment in the raw material mill system is also increasing. At present, the diameter of the ball mill has reached 5–6 m, and the unit output can reach more than 300 t/h. The unit production capacity of the vertical mill and roller press can be as high as 640 t/h, which can be well matched with the 2000 t/d–12,000 t/d production line.

A more comprehensive understanding of the characteristics of these common raw material grinding systems, grasping the problems that are likely to occur in use, and seeking the reasonable improving methods and measures, can provide a reference for further energy conservation in the industry as a whole. The following is a detailed introduction to the three mainstream systems, which is convenient for the enterprises to make a reasonable selection and transformation of the raw material mill system in production.

## 3. Three Types of Mill Raw Material Preparation System

### *3.1. Middle Unloading Drying Tube Mill Raw Material Preparation System*

The tube mill process technology is very common in the earlier construction of the production line, which has the characteristics of strong adaptability to the fluctuation of the physical properties of the material, and easy adjustment of the product fineness and particle gradation. The mill has a simple structure which is easy to manage and maintain. The disadvantage is consuming a lot of electricity, especially when it is used to process materials with low moisture content and easy to grind. The air required for air sweeping and lifting of the material is greater than the hot air required for drying the material, so it is not energy-saving. Due to the high electricity consumption of the tube mill system, it has been gradually giving way to the vertical mill or roller press system at this stage. However, for the production of special cements, such as oil well cement, the advantages of tube mills can still be used.

The middle unloading drying tube mill is one of drying and grinding, equivalent to the combination of air sweeping mill and tail unloading circulating mill in the drying effect. In terms of mill action, it is actually equivalent to a two-stage circuit, which is higher than the air sweeping mill and tail unloading circulating mill, and is suitable for large-scale production.

The front end of the middle unloading drying tube mill is equipped with a drying chamber. The resistance of the middle unloading grate is small. Hot air can enter from both ends. However, most of the hot air enters from the mill head, for when the material in the rough mill chamber is coarse, the proper material bed surface can be maintained when the air speed is appropriately increased, so the ventilation in the mill is large and the drying capacity is strong. The air speed is higher in the coarse grinding chamber than that in the fine grinding chamber, so it has a very good drying effect and does not cause excessive mill. If the waste gas with a certain amount of heat in the kiln tail is used, the raw

materials with a moisture content of less than 6% can be dried. If a heat source is added to provide high temperature hot air, the materials with a moisture content of 14% can be dried. The mill is equipped with two grinding chambers, and the ball of the grinding chamber can be adjusted appropriately in accordance with the material conditions. There is no need for particularly strict requirements on the particle size of the mill material. The maximum mill material particle size can reach 25 mm. In order to improve the flowability of the material in the drying chamber, an appropriate amount of powder returning from the classifier can be added to the feed during production. The ratio of powder returning from the mill head and that from the mill tail is generally 1:2. The two-stage circuit has less over-grinding phenomenon and high grinding efficiency, which is especially suitable for the working conditions of raw material products requiring uniform and coarser particle size, and no large specific surface area. Due to its good adaptability to raw materials, it has been extensively developed in the ball mill system [7]. The electricity consumption of the middle unloading lifting cycle mill raw material is relatively low. The better status is that the electricity consumption of the mill is 15 kWh/t, and the system electricity consumption is about 20 kWh/t [8]. However, its heating and air supply systems are more complicated, and strict air lock should be an issue worthy of more attention.

The middle unloading drying tube mill is a kind of tube mill process. Though its electricity consumption cannot be compared with that of the vertical mill, it still has the advantages of low equipment failure rate, easy and convenient maintenance, reliable operation, strong adaptability to materials, good drying effect, good grinding ability, and more convenient fineness adjustment [9]. There are still a considerable number of enterprises in China still applying this mill process, especially those established in the earlier years. The middle unloading drying mill has low investment, simple maintenance and management, and high equipment operation rate, which is beneficial to the advantage of the factory, shortening the debugging time, generating benefits as soon as possible, and facilitating production management. The operation of the middle unloading drying mill system is relatively simple during normal production, but it is very easy to cause problems such as material blocking in the mill chute at the initial stage of commissioning. Therefore, it is very necessary to take some corresponding measures to distinguish different situations at various stages of the load test [10].

### *3.2. Vertical Mill Raw Material Final Mill System*

The domestic and foreign cement industry production lines mainly use vertical mill systems as the mainstream for raw material grinding. Because vertical mills are grinding equipment that integrates grinding, drying, and powder selection, and it has the characteristics of high grinding efficiency, simple technological process, convenient operation, and maintenance, small building area and space use, clean operating environment, and low wear, it is favored by the majority of cement manufacturers. The main features of the vertical mill are high grinding efficiency, strong drying capacity, stable chemical composition of the product, and uniform particle size distribution [11,12], which is beneficial to calcination.

Today, with the rapid development of grinding technology, in the raw material grinding of cement production lines, China has improved from the commonly-used traditional raw material vertical mill process system to a full external circulating raw material vertical mill preparation system. The traditional raw material vertical air sweeping mill is equipped with a powder separator above the mill, and the material circulates in the mill. Therefore, a large amount of air needs to be passed into the mill. The high-speed jet airflow from the nozzle ring will bring the ground material into the powder separator, therefore, the fan of this internal circulating vertical mill system consumes relatively large electricity, and its energy consumption index has no obvious advantage. The electricity consumption per single vertical mill is basically 8–11 kWh/t, while the electricity consumption of the system is basically maintained at 14–19 kWh/t. Though this process is more energy-saving than

that of the tube mill, it is difficult to further reduce its electricity consumption because it belongs to the air sweeping mill system.

The full external circulating raw material vertical mill preparation system has its own process characteristics, which are specifically shown in: (1) Compared with the traditional vertical mill process, it can effectively prevent the over-mill phenomena and reduce the electricity consumption of the mill main machine and the fan. (2) The vertical mill does not have a powder separator. Its advantages are: Firstly, compared with the traditional internal circulating vertical mill, the materials are all mechanically upgraded, which reduces the electricity consumption of the material conveying in the mill and the electricity consumption of the system's fan. Secondly, the external movement of the powder separator can be specially designed in accordance with different grinding processes, which is conducive to the implementation of high-efficiency and energy-saving powder separating technology. Finally, the nozzle ring setting in the mill is canceled, which greatly slows down the wearing of the grinding roller, the inner wall of the shell, and other parts by the high-speed dust-containing airflow. (3) By making full use of the grinding principle of the roller grinder, the material in the mill area of the grinders is both affected by the squeezing force and the shear force caused by the relative speed, making it easier to obtain high-efficiency grinding. The special mill roller design enlarges the mill area of the material. With the specially-designed armour plate, it can achieve uniform pressure on the material layer. Whether it is high-strength compression or shear mill, it has excellent mill efficiency. (4) The material dispersing effect is good after grinding. Since the mill process is the combined effect of shearing and extrusion forces, the material from the vertical mill is loose, which greatly reduces the electricity consumption of material dispersion and classification in the subsequent powder selection process. The materials are evenly dispersed in the V-type powder separator, and the powder selection efficiency is high, so the powder selecting air volume can be reduced, and the electricity consumption of the system's fan can be effectively reduced.

The electricity consumption of the full external circulating raw material vertical mill is further reduced on the basis of the lower electricity consumption of the air sweeping vertical mill. The reason is that the design of the V-type static powder separator is different from that of the V selection in the roller press grinding system. The resistance of the air separating system is reduced by 30–35%, and the power of the circulating fan can be reduced by 40–45%, which has a certain energy-saving purpose. The power consumption of the system can be reduced to less than 13 kWh/t after using the full external circulating raw material vertical mill.

### *3.3. Roller Press Raw Material Final Mill System*

Roller press is used for raw material and cement grinding, known for their high efficiency and energy saving. In the 21st Century, after the successful test of the large-scale roller press final mill system designed and developed in China, it has been widely used home and abroad. Especially in many domestic factories, in order to adapt to the expansion of production scale, it is very common to replace the traditional ball mill grinding system with it. In the raw material grinding system, the roller press generally adopts the final grinding process.

Compared with the vertical mill system, the characteristics of the final mill system of the roller press are higher grinding efficiency and lower electricity consumption, lower metal consumption, some up to 0.5 g/t raw material, less equipment, simpler process, easier installation, smaller size and space, lower civil construction cost and noise, and larger particle size of the material entering the mill operation. From the actual operation point of view, the actual production capacity exceeds the designed production capacity, and the economic and technical indicators are better than that of the vertical mill system. Because the roller press system has been nationalized, the equipment and spare parts are easy to purchase and maintain, and low in cost. The final mill system of the roller press

used for raw material preparation has gradually shown its technical advantages, and has been widely and highly praised by the users [10].

Compared with the single-point contact grinding principle of ball mill, the energy-saving of roller press and vertical mill is entirely due to the principle of material bed pulverization. That is, the material is pulverized as a layer or a material bed. Under a high pressure, the particles are completely broken. Compared with the vertical mill, the pressure of the material bed of the roller press is about 10 times that of the vertical mill, so the total high pressure of the roller press is very big, the fine powder produced has microcracks, the fine powder particles are all needle-shaped or flakes-shaped, and the raw material is easier to burn. The main monitoring parameters are: Rolling motor/fixed roller pressure, cake thickness (left and right roll gap), rolling /fixed roller motor current, dynamic powder separator inlet and outlet negative pressure, circulating fan current, external circulation bucket elevator current, the inlet temperature of the dynamic powder separator, and the bucket elevator current for the raw material warehousing. During operation, special attention should be paid to the stability of the upper bin weight of the roller press, the moisture and particle size of the material entering the roller press. And the rapid explosive vibration of the roller press when the fine powder content of the material entering the roller press is too high. When it contains clay, attention should be paid to its moisture content. When the plasticity is too high, it will easily adhere to the roll surface, which will cause the extrusion effect to decrease [7].

The roller press raw material final mill system has low electricity consumption and high operational availability of the main and auxiliary equipment, which is the direction of the selection and transformation of raw material preparation equipment. When selecting the conveying equipment, a surplus factor must be reserved to avoid the bottlenecks in the system, the existing enterprises that use the middle unloading drying tube mill to prepare raw material should actively create conditions to adopt the roller press raw material final mill system to fully tap the electricity-saving potential of the raw material mill system [13].

## 4. Comparison of Three Types of Raw Material Mill Systems and Analysis of the Factors Affecting Operation

In order to have a comprehensive understanding of the performances of the three raw material final grinding systems, the current three major series of commonly used large-scale raw material mill models and technical indicators such as production capacity are listed Table 1, combined with the survey and research results of the project team.

**Table 1.** Models and technical indicators of common large-scale raw material mills.

| Country | Mill Type and Specifications | | Installed Power (kW) | Output (t/h) | Electricity Consumption * (kWh/t) |
|---|---|---|---|---|---|
| **China** | Middle unloading drying tube mill Φ4.6 m × (10 + 3.5)m | | 2 × 3550 | 380–480 | 20–24 |
| | External circulation vertical mill | TRM53.4 | 4000 | 410–440 | 15–17 |
| | | TRM56.4 | 4000–5500 | 460–590 | 13–15 |
| | | HRM480 | 3800 | 380–450 | 13–17 |
| | Roller Press | HFCG200-180 | 2 × 2000 | 520 | 12–17 |
| | | TRP(R)220-160 | 2 × 1800 | 470–510 | 12–13 |
| | | CLF180120-D-SD | 2 × 1250 | 260 | 14–22 |
| **Denmark** | Vertical mill | ATOX50 | 3800 | 380 | 17–20 |
| **Germany** | Vertical mill | LM48.4 | 2700 | 320 | 22 |
| | | RMR57/28/555 | 4200 | 430–450 | 17 |

* Remarks: The electricity consumption value is the data of the actual operation of the surveyed company. Due to the differences in the raw materials' quality and the management of different companies, this data cannot be used to evaluate the product quality of the manufacturer or to rank the electricity consumption of common products of the production equipment.

### *4.1. Comparison of Technical Indicators of Three Raw Material Mill Systems*

The middle unloading drying tube mill, vertical mill, and roller press final mill can provide corresponding options for various tonnage production lines. In the surveyed

enterprises, the middle unloading drying tube mill system always has a grinding blind zone during the rough and fine mill process, and cannot form a material bed. Among the above several grinding systems, its electricity consumption for raw material preparation is the highest, mostly in the range of 20–24 kWh/t. Vertical mills make use of high-efficiency material bed grinding. Due to the different grindability of the materials, and the improper use of equipment or insufficient maintenance, the electricity consumption will fluctuate accordingly. The electricity consumption of the external circulating vertical mill raw material grinding system is mostly 13–17 kWh/t, and the electricity consumption of the internal circulating vertical mill raw material grinding system is mostly 17–22 kWh/t. The roller press raw material final mill system gives full play to the technical advantages of the roller press extrusion grinding. Due to the low installed electricity of the system, the electricity consumption of raw material mill is relatively low, mostly in the range of 12–22 kWh/t. The unlisted roller press combined grinding system process is more complicated and has very few application. The electricity consumption of raw material preparation is higher than that of the vertical mill system, which is close to the middle unloading drying tube mill, generally 20–22 kWh/t. Hence, the roller press raw material final mill saves the most energy and should be promoted and widely applied.

### *4.2. Selection Principle of Different Raw Material Mill Systems*

Combined with the aforementioned analysis of the characteristics, technologies, existing problems, and improving measures of the three mill systems, the selection of the three mill systems can be carried out in accordance with the following principles:

Generally, the raw material with good grindability and high moisture content can select a middle unloading drying mill, which has low investment, less difficulty in maintenance and management, and high equipment-operating rate. The use of the middle unloading drying mill system is beneficial to the advantage of the factory, shortening the debugging time, generating benefits as soon as possible, and facilitating production management.

Vertical mills can be chosen for those with poor grindability and moderate moisture, which are high grinding efficiency, strong drying capacity, stable chemical composition of the product, and uniform particle size distribution, beneficial to calcination. The technological process is simple, the construction area and space use are small, the operating environment is clean, the wear is small, and the utilization rate is high.

A roller press final mill can be chosen for those with moderate grindability and moisture content, whose characteristics are high mill efficiency, lower electricity consumption than vertical mill systems, low metal consumption, small size and space, and easy installation.

For raw material mills, both vertical mills and roller press final mill systems can achieve lower energy consumption, and have become a more common raw material mill process nowadays. It can be seen from the common process that in the process of raw material grinding. The use of kiln tail air to suspend drying materials, the use of circulating air into the air classifier for sorting material, and the use of related conveying equipment for transporting material are all very important processes. Therefore, the raw material grinding process, system air leakage, loss of related equipment, and the performance of the raw material entering the mill all have a certain impact on the energy consumption of the raw material mill system.

### *4.3. Analysis of the Factors Affecting Electricity Consumption of Raw Mill System*

There are many factors that affect the electricity consumption of the raw mill system, including the mill process, the type, specification, and model of the mill, the physical properties of the material (moisture, particle size, grindability, natural accumulation angle, etc.), the amount of feed and uniformity, product fineness, powder selection efficiency, circulating load, hot air temperature, fan efficiency and ventilation volume, etc. Since the three previous grinding systems have been analyzed from the aspects of the grinding process, the types specifications and models of mills, and the maintenance of the system

equipment, we will only summarize the performance of the raw materials entering the mill and the air leakage of the system.

(1) Granularity and grade of raw materials

The raw material ingredients mainly include limestone, sandstone or shale, iron powder, or iron ore. Considering the comprehensive utilization of industrial solid waste, some companies also introduce steel slag, copper slag, iron tailings, fly ash, or slag. Limestone occupies the highest proportion of raw materials, ranging 80–83%, and is the most important component of raw materials and one of the raw materials that need to be paid much attention to in mills.

The middle unloading drying tube mill has a wide adaptability of particle size. However, when the particle size exceeds 25 mm, it is easy to cause a decrease in output.

Vertical mills have certain requirements for the particle size. When the particle size of limestone in the grinding material is too large, the excessively large particles will continuously and instantaneously support the mill roller, failing to form a better mill layer. When the material layer is unstable, the vibration value of the mill is large, and even grinding vibration stops, which affects the operating efficiency of the mill and causes the shift output to decrease [14].

Roller presses are more sensitive to the particle size of the raw materials, which has a great impact on the output and the stable operation of the roller press. When the particle size is not uniform, the deviation of the roll gap on both sides of the roller press is large, the roll gap fluctuates and corrects frequently, the vibration of the roller press is large, and the work is unstable [15].

Of course, when there are iron-containing steel slag, or sandstone containing well-crystallized quartz, or limestone containing tunnels, the raw material has poor grindability. After the raw material enters the mill, the amount of spitting will increase, and so does the amount of external circulation, which makes the output of the mill significantly decrease. In this case, it is very necessary to adopt regular slag removal or secondary iron removal and other technological means.

(2) Moisture content of feed material

During the preparation process of cement raw material, the material moisture is an important control index. The production practice shows that the comprehensive moisture content of the material entering the mill largely restricts the hourly output and the electricity consumption of the raw mill, and the production cost. Relatively speaking, the air sweeping vertical mill has the strongest drying capacity and the best adaptability to moisture. The moisture content of the grinding material can be relaxed to 10–15%. The external circulating vertical mill has a relatively higher requirement for water adaptability, which is generally required to be controlled below 3%.

For tube (ball) mill, when the material moisture is big (generally comprehensive moisture > 2.5%), the output of the raw material mill will decrease significantly. On the one hand, when the material moisture is big, it affects the uniform feeding and prolongs the feeding time. On the other hand, when the wet material is fed too much, it may cause a full mill or stick a thick layer of wet material on the inner liner of the mill, which will have to be stopped.

For roller presses, it is more sensitive to moisture content. When the moisture is big, the materials will stick together after entering the pressure zone, which will increase the cushioning effect of the materials and decrease the extrusion efficiency. The research of Q. Heng et al. [16] showed that: For the roller press, it is best to control the comprehensive moisture content of the material entering the roller press to be less than 1.5%. If the comprehensive moisture content of the raw materials is big, the drying of the materials in the V-type powder separator and pipeline should be strengthened to improve the drying efficiency of the powder separator and drying system.

(3) System air

In the new drying process production, the fan is the key and indispensable equipment for material transportation, raw material preparation, clinker calcination, cement produc-

tion, dust collection, and other important links. It is the equipment with the largest total installed capacity and has important functions and significance. For the raw material mill system, the system air temperature, air speed, and air volume directly affect the output of the mill. The proper selection and efficient management of fans are also the guarantee for saving energy. Only by reducing the deviation of the ventilation system and overcoming the common errors in operation can the goal of saving energy, and stable and efficient operation, be achieved [9].

The first is to pay attention to the fact that the fluid medium of the raw mill system is different from the general air, which is a high-temperature and high-dust medium, and which requires regular cleaning of the parts that are easy to accumulate dust. Otherwise the cross-sectional area of the pipeline will become smaller. When the pressure loss increases, the air speed and flow will decrease, which seriously affects the output and increases the electricity consumption.

The second is to strengthen and improve the technical management of the ventilation system of the raw material mill system and the regular maintenance of equipment, and to maintain the air tightness of the pipeline. The air leakage is not allowed to exceed the specified value, otherwise it will affect the high temperature fan, circulating fan, and/or tail exhaust fan and make the efficiency of fan operation decrease. For example, when the air leakage causes the negative pressure of the pipe at the outlet of the raw material mill to decrease, the amount of air out of the raw material mill will decrease, and the drying capacity will also decrease, so the output and electricity consumption will be affected accordingly. At the same time, when the air leakage increases, and the load of the tail exhaust fan will be increased.

The third is to properly replace the windshield with the frequency conversion technology transformation to adjust the air volume. It is easy to reduce fan vibration, eliminate the current impact of large motor startup, avoid mechanical vibration, greatly reduce equipment failure rate, and reduce equipment variable maintenance workload. The frequency conversion technology does not only greatly reduce the daily energy consumption and save electricity consumption, so that the economic benefits become more obvious, but also the fan operates in a better state, with low vibration value and no noise.

After all, there are many factors that affect the operation of the raw material mill, which will not be repeated here in view of the length.

## 5. Conclusions

Between 2014 and 2019, the project team collected production data through thermal calibration of cement production lines, and visited and mastered the electricity consumption of about 1005 clinker production lines in the raw material preparation process. The average electricity consumption of the raw material preparation process of all clinker production lines between 2014 and 2019 was 25.2 kWh/t. The average electricity consumption of different-tonnage production lines varies with time. In comparison with high-tonnage ones, the electricity consumption of low-tonnage production lines has wider distribution and higher average value. The average electricity consumption of raw material mill has dropped from 30.88 kWh/t in 2014 to 16.13 kWh/t in 2019, a drop of more than half.

The middle unloading drying tube mill, vertical mill, and roller press final mill can provide corresponding options for various tonnage production lines. Among the several grinding systems, its electricity consumption for raw material preparation is the highest, mostly in the range of 20–24 kWh/t. The roller press raw material final mill system gives full play to the technical advantages of the roller press extrusion grinding. Due to the low installed electricity of the system, the electricity consumption per ton of raw material mill is relatively low, mostly in the range of 12–22 kWh/t.

There are many factors that affect the electricity consumption of the raw mill system, including the mill process, the type, specification, and model of the mill, the physical properties of the material (moisture, particle size, grindability, natural accumulation angle, etc.), the amount of feed and uniformity, product fineness, powder selection efficiency,

circulating load, hot air temperature, fan efficiency and ventilation volume, etc. So in the choice of grinding system, each company should choose according to their own situation.

**Author Contributions:** Conceptualization, Q.Z.; formal analysis, R.M.; investigation, Q.L.; methodology, M.W.; resources, M.Z. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Ministry of Science and Technology of the People's Republic of China, grant number 2014FY110900.

**Acknowledgments:** We are gratefully acknowledged the financial support from the Ministry of Science and Technology of the People's Republic of China, National Science and Technology Basic Work Project (Project No.: 2014FY110900).

**Conflicts of Interest:** To the best of our knowledge, the named authors have no conflict of interest, financial or otherwise.

## References

1. Ma, X.; Li, C.; Li, B. Carbon Emissions of China's Cement Packing: Life Cycle Assessment. *Sustainability* **2019**, *11*, 5554. [CrossRef]
2. Wang, Z.; Zeng, R. *Cement Mill Technology and Progress*; China Construction Industry Press: Beijing, China, 2008.
3. Atmaca, A.; Kanoglu, M. Reducing energy consumption of a raw mill in cement industry. *Energy* **2012**, *42*, 261–269. [CrossRef]
4. Cai, X. *Research on Intelligent Control System of Cement Raw Material Vertical Mill*; University of Jinan: Jinan, China, 2014.
5. Zhou, Y. *Research on Key Equipment of Cement Production and Its Energy-Saving and Consumption-Reducing Technology*; Wuhan University of Technology: Wuhan, China, 2010.
6. Wu, Z.; Zou, Y.; Wu, Y. Improvement of Technology and Equipment of Air Sweeping Raw Material Mill System. *China Cem.* **2013**, *6*, 94–95.
7. Li, X.; Zhang, H. Comparison of Raw Material Final Mill Schemes between a Middle Unloading Drying Mill, a Vertical Mill and a Roller Press. *Cement* **2010**, *10*, 42–43.
8. Sun, G.; Wang, J.; Hu, T. Analysis on Energy-saving Technology Transformation of Raw Mill System. *Low Carbon Real Estate* **2016**, *2*, 145–146.
9. Zhang, H.; Li, T.; Qi, J. Methods and Measures to Improve the Operating Efficiency of Wind Turbines. *China Cem.* **2013**, *10*, 67–71.
10. Zhao, J.; Sui, L. The Necessity of Reducing the Moisture of the Material Entering the Mill. *Cem. Technol.* **1998**, *1*, 45–46.
11. Pilevneli, C.C.; Kızgut, S.; Toroğlu, İ.; Çuhadaroğlu, D.; Yiğit, E. Open and closed circuit dry grinding of cement mill rejects in a pilot scale vertical stirred mill. *Powder Technol.* **2003**, *139*, 165–174. [CrossRef]
12. Jankovic, A.; Valery, W.; Davis, E. Cement grinding optimisation. *Miner. Eng.* **2004**, *17*, 11–12. [CrossRef]
13. Zhou, B.; Wang, Y. Evaluation of Typical Raw Material Preparation System in China's Cement Industry. *New Century Cem. Guide* **2014**, *20*, 29–33.
14. Wang, X. How to Do Economical Operation of Raw Material Preparation System. *Cement* **2016**, *8*, 11–14.
15. Wang, J.; Zhong, G.; Zhong, Y.; Kang, Y. Analysis of Factors and Measures for Stable Operation of Raw Material Final Mill System of Roller Press. *Cement* **2018**, *9*, 34–37.
16. Heng, Q.; Li, H.; Li, H. The Influence of Material Characteristics on the Roller Press Combined Mill System (Part 1). *Cem. Technol.* **2011**, *2*, 47–50.